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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G21B 1/00	A1	(11) International Publication Number: WO 90/13125
		(43) International Publication Date: 1 November 1990 (01.11.90)

(21) International Application Number: PCT/US89/01749

(22) International Filing Date: 26 April 1989 (26.04.89)

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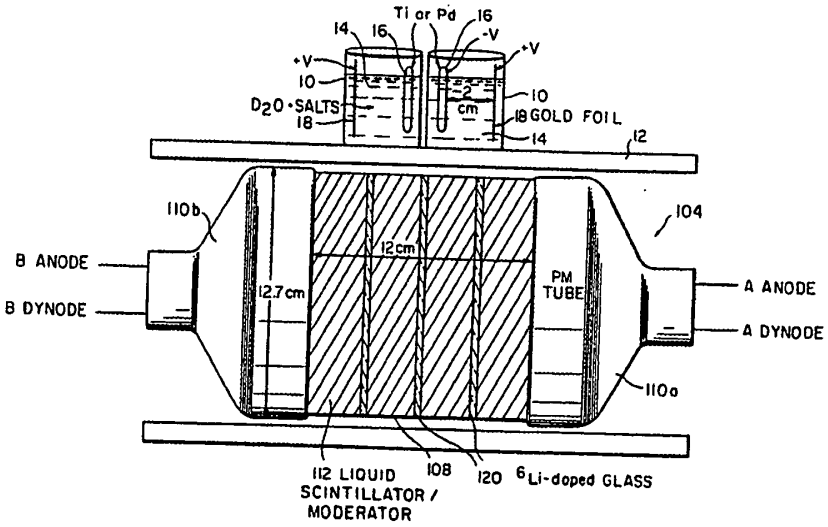
(81) Designated States: AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CF (OAPI patent), CG (OAPI patent), CH, + CH (European patent), CM (OAPI patent), DE, DE (European patent), DK, FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, RO, SD, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.

Published
With international search report.

(54) Title: PIEZONUCLEAR FUSION



(57) Abstract

A method of promoting nuclear fusion by infusion of fusible nuclei into a material, such as palladium or titanium.

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PIEZONUCLEAR FUSION

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Background of the Invention

Fusion of isotopic hydrogen nuclei is the principal means of producing energy in the high-temperature interiors of stars. In relatively cold terrestrial conditions, the nuclei are clothed with electrons and approach one another no closer than allowed by the molecular Coulomb barrier. The rate of nuclear fusion in molecular hydrogen is then governed by the quantum-mechanical tunneling through that barrier, or equivalently, the probability of finding the two nuclei at zero separation. In a deuterium molecule, where the equilibrium separation between deuterons (d) is 0.74 Angstroms, the d-d fusion rate is exceedingly slow, about 10^{-70} per D_2 molecule per second [Van Siclen, C.D. & Jones, S.E. Journal of Physics G. Nucl. Phys. 12, 213-221 (1986).].

By replacing the electron in a hydrogen molecular ion with a more massive charged particle, the fusion rate is greatly increased. In muon-catalyzed fusion, the internuclear separation is reduced by a factor of approximately 200 (the muon to electron mass ratio), and

the nuclear fusion rate correspondingly increases by roughly eighty orders of magnitude [Van Siclen et al., op. cit.]. Muon-catalyzed fusion has been demonstrated to be an effective means of rapidly inducing fusion reactions in low-temperature hydrogen isotopic mixtures [Jones, S.E. Nature 321, 127-133 (1986); Rafelski, J. & Jones, S.E. Scientific American 257, 84-89 (July 1987).]. Muons can catalyze fusion of hydrogen isotopes. Catalysis lowers the activation energy (in this case, the coulomb barrier) without using up or destroying the catalyst. A muon brings hydrogen nuclei very close together. Quantum-mechanical tunnelling then results in fusion. Each muon promotes fusion quickly (10^{-12} seconds for deuteron-triton fusion), and is usually released to participate in another fusion. However, muons decay naturally and the number of fusions during a muon lifetime cannot be made large enough to offset the high cost of producing muons.

Concentration anomalies of ^{3}He have been reported in metal foils by Mamyrin et al., Sov. Phys. Dokl. 23, 581 (1978). Among several possible explanations, Mamyrin et al. suggest an "analog" of muon catalysis. These observed concentrations of ^{3}He might also be explainable by cold piezonuclear fusion. That is to say, electrolytic refining of the metals in deuterium-bearing water could have provided conditions for cold nuclear fusion. However, if cold nuclear fusion occurred during such metal refining operations, it was heretofore wholly unappreciated.

A hypothetical quasi-particle a few times as massive as the electron would increase the cold fusion rate to readily measurable levels, about 10^{-20} fusions per d-d molecule per second [Van Siclen et al., op. cit.].

In 1926, Paneth and coworkers reported transmutation of hydrogen into helium during electrolysis of ordinary water using a palladium electrode. Naturwissenschaften,

14:956-62 (1926); Chem. Abs. 21:357. They subsequently recanted this claim, concluding instead that the observed helium had not been produced from hydrogen, but instead had been released from glass and asbestos present in their experimental apparatus. Naturwissenschaften, 15:379 (1927); Chem. Abs. 21:2422.

The nuclear fusion of light nuclei provides more energy from a smaller amount of fuel than any other process. Since the energy of nuclear fusion was first demonstrated in thermonuclear weapons research, attempts have been made to harness fusion for peaceful purposes. However, intense research that began in the 1940's has still not provided an economical and controllable source of power based on nuclear fusion. The need for such sources is long-standing and as yet unfilled. Prior attempts have focussed on creation of ultra-high temperature and pressure conditions by application of magnetic fields, energy beams, etc. and have not succeeded in producing controlled fusion without extreme energy inputs. The most advanced reactors (e.g. tokomaks and laser-fusion systems) are large, expensive and impractical.

Ideal reactors would operate at temperatures low enough for common materials to be used for construction. They should control the rate of fusion so it could be entirely off, or else run at any useful level without danger of explosion, meltdown, or any type of disaster. The equipment should be reasonably small, simple, safe, and inexpensive. And, of course, the fuel and equipment costs should be comparable to those of competing methods of generating power and/or useful radiation.

Summary of the Invention

The present invention provides a new method of promoting nuclear fusion in a controlled fashion under moderate conditions. We have discovered a means of

inducing nuclear fusion without the use of either high temperatures, pressures, or radioactive muons.

Without being bound to a particular theory, it appears that in accordance with the invention a distortion of the internuclear hydrogen wavefunction sufficient to achieve detectable levels of nuclear fusion can be realized under certain conditions when hydrogen isotopic nuclei are loaded into metallic crystalline lattices or other forms of condensed matter. It appears that the rate of nuclear fusion increases many-fold if the nuclei can be brought substantially closer together than their normal distance in chemical bonds. In this invention, the desired proximity is achieved through pressure or the use of catalytic sites or both. The applicants have coined the term "piezonuclear fusion" or PNF from the latin root "piezo" for squeezing or pressure as a designation for nuclear fusion achieved by the method of the invention.

A particularly preferred embodiment involves fusion of deuterium nuclei in an electrolysis cell. We have observed the energetic neutrons at the appropriate 2.5 MeV level for D-D fusion, and indications of the 5.4 MeV gamma rays expected when such fusion occurs between hydrogen and deuterium nuclei. Other nuclei can also be used, as can other types of reactors (e.g. loading selected metals with high pressure hydrogen isotopes). Possible fusion reactions which may be carried out according to the method of the invention include:

$$P + D \rightarrow {}^{3}He + \gamma(5.4MeV)$$

$$D + D \rightarrow T(1.01MeV) + p(3.02MeV) \quad 50\%$$

$$\rightarrow He^{3}(0.82MeV) + n(2.45MeV) \quad 50\%$$

$$D + T \rightarrow He^{4}(3.5MeV) + n(14.1MeV)$$

$$D + He^{3} \rightarrow He^{4}(3.6MeV) + p(14.7MeV)$$

$$T + T \rightarrow He^{4} + 2n + 11.3MeV$$

$$He^3 + T \rightarrow He^4 + P + n + 12.1MeV$$

51%

$$\rightarrow He^4(4.8MeV) + D(9.5MeV)$$

43%

$$\rightarrow He^5(2.4MeV) + p(11.9MeV)$$

6%

$$p + Li^6 \rightarrow He^4(1.7MeV) + He^3(2.3MeV)$$

$$p + Li^7 \rightarrow 2He^4 + 17.3MeV$$

20%

$$\rightarrow Be^7 + n - 1.6MeV$$

80%

$$D + Li^6 \rightarrow 2He^4 + 22.4MeV$$

$$p + B^{11} \rightarrow 3He^4 + 8.7MeV$$

$$n + Li^6 \rightarrow He^4(2.1MeV) + T(2.7MeV)$$

Depending upon the materials used, the fusion can produce neutrons, gamma (and other) radiation, and thermal energy. All of these are useful products of the invention. The radiation can be used for nondestructive testing and imaging as well as promoting nuclear and chemical reactions. The thermal energy can be used for heating, for the production of electricity, and for power production in general.

Because the fusion rate increases as the distance between nuclei decreases, methods that compress pairs of nuclei are desirable. In addition, the electrical repulsion of the nuclei (coulomb barrier) can be decreased if electron density is high between the nuclei. The following embodiments are believed to achieve one or both of these catalytic actions. For maximum efficiency, the catalytic sites should be reusable (i.e., catalyze many fusion events). This implies preservation of the structure. removal of the ash (e.g. ^3He) and minimal blockage by materials that fuse slowly or not at all (e.g. H_2). The method of the invention makes use of pressure near charged interfaces, codeposition, and

structure of electroplated solids (both the phase and crystalline aspects of structure) to promote nuclear fusion.

Brief Description of the Drawings

The invention will be explained in further detail hereinafter with reference to the accompanying drawings in which:

Fig. 1 is a schematic representation of an apparatus in accordance with the invention and used to carry out the method of the invention;

Fig. 2 is a schematic representation of an individual electrolysis cell;

Figs. 3a and 3b are graphs of neutron spectra confirming the occurrence of fusion;

Figs. 4a and 4b are schematic representations of an apparatus for carrying out an alternate embodiment of the method of the invention;

Fig. 5 is a schematic diagram of another apparatus useful in carrying out method of the invention;

Fig. 6 is a schematic view of an electrolysis cell for codepositing fuel and catalytic site material;

Fig. 7 is a schematic representation of a cell for piezonuclear reaction by compression of fuel;

Fig. 8 is a schematic illustration of an arrangement for inducing shock promoted piezonuclear fusion;

Figs. 9a and 9b are a schematic block diagram of the circuitry used by the neutron counter illustrated in Fig. 1.

Fig. 10 is a graphic representation of an energy spectrum obtained during the method of the invention juxtaposed with the background spectrum;

Fig. 11 is a graphic plot of the differences between radiation values measured during the method of the invention and background measurements;

Fig. 12 is a graph of the ratios of measured radiation levels to background radiation levels during fourteen specific tests of the method of the invention.

Detailed Description of Preferred Embodiments

Deuteron-deuteron fusion at room temperature has been observed when deuterons have been infused into a metal, such as titanium, palladium, or nickel. The fusion reaction

$$d + d \rightarrow {}^{3}He(0.82\ MeV) + n(2.45\ MeV) \qquad (1a)$$

is evidently catalyzed in the metal lattice. Neutrons having approximately 2.5 MeV energy have been clearly detected with a sensitive neutron spectrometer.

We have not yet obtained results regarding the parallel reaction

$$d + d \rightarrow p(3.02\ MeV) + t(1.01\ MeV) \qquad (1b)$$

as this requires different measuring procedure. However, it can be presumed that the reaction (1b) occurs at a nearly equal rate as the reaction (1a), which is usually the case.

Metals having the capability to absorb and hold hydrogen may be used as catalyst materials in the invention. Titanium, platinum and palladium have been found to be particularly suitable catalyst materials because of their large capacities for holding hydrogen and forming hydrides. Titanium and palladium are particularly preferred. Other possible catalyst materials include lanthanum, nickel, iron, copper, zirconium, tantalum, thorium alloys and lithium-aluminum hydride.

Electrolytic Fusion: In one preferred arrangement, the method of the invention is carried out

in an electrolytic cell comprising a negative electrode of hydrogen absorbing, electrically conductive material, a positive counterelectrode and an electrolyte containing fusionable nuclei. A suitable arrangement is illustrated schematically in Fig. 1, which shows a pair of electrolytic cells on top of a neutron spectrometer. Fusion has been found to occur during low-voltage electrolytic infusion of deuterons in such a system as d^+ and metal ions from the electrolyte are deposited at (and into) the negative electrode.

In Fig. 1, a plurality of glass vessels 10 are placed on a support 12. Fig. 2 is an enlarged schematic representation of an individual cell. Approximately 20 ml of a heavy water electrolyte solution 14 are introduced into each vessel 10, and a negative electrode 16 and a positive counterelectrode 18 are also disposed in each vessel in contact with the electrolyte solution. Electrodes 16 and 18 are appropriately connected by electrical leads 20 and 22 to a source of electrical potential, such as a battery 24.

Adjacent the vessels 10 is a neutron detector 104 comprising a pyrex glass tube 108 filled with a liquid moderator/scintillator 112 which emits light when traversed by a neutron. Several ^6Li-doped glass plates 120 are also disposed in tube 108. Scintillation detectors in the form of photomultiplier tubes 110a and 110b are provided to detect light from the liquid scintillator and the scintillating glass plates. The detector and its associated electronics are described more fully below.

Deuteron enriched aqueous salt solutions have been successfully used as electrolytes. A currently preferred electrolyte solution comprises a mixture of 800 parts by weight deuterium oxide (D_2O) plus approximately 1 part by weight of each of the following metal salts: $FeSO_4 \cdot 7H_2O$, $NiCl_2 \cdot 6H_2O$, $PdCl_2$, $CaCO_3$, $Li_2SO_4 \cdot H_2O$, $NaSO_4 \cdot 10H_2O$,

$CaH_4(PO_4)_2 \cdot H_2O$, $TiOSO_4 \cdot H_2SO_4 \cdot 8H_2O$, and a very small amount of AuCN. The pH is adjusted to pH $\leq$ 3 with HNO_3. Experimental evidence suggests it is advantageous for co-deposition of deuterons and metal ions to occur at the negative electrode. The metal ions typically come from the electrolyte, but they may also result from the anode if a consumable anode is employed.

A number of factors probably influence the rate of fusion in this electrolytic embodiment. These parameters include voltage, current density, temperature, electrolyte concentration, materials being plated out, and rate of stirring. They work together to produce pressure at and near the solid-liquid interface, to supply atomic and molecular hydrogen in various stages of oxidation, and to plate solids with microstructure capable of catalyzing nuclear fusion.

In particularly preferred embodiments of the invention, individual electrodes consisted of approximately 3 g purified "fused" titanium in pellet form, or of 0.05 g of 0.025 mm thick palladium foils, or of 5 g of mossy palladium.

The electrolytic method may be carried out in individual electrolytic cells, or it may be carried out in groups of plural cells. Typically four to eight cells have been used in the experimental tests reported herein in order to increase the total number of neutrons generated in the tests.

If fouling of the electrodes occurs during the method of the invention, the electrodes may be cleaned and reused. For example, palladium pieces can be re-used after cleaning and roughening the surfaces with dilute acid or abrasives.

Hydrogen bubbles have been observed to form on the cathode only after several minutes of electrolysis, suggesting the rapid absorption of deuterons into the

cathode material; oxygen bubbles form at the anode immediately.

The counterelectrode or positive electrode may be any material which makes suitable electrical contact with the electrolyte. In a particulary preferred embodiment a gold or platinum foil is used for the positive electrode because of its low reactivity, high conductivity and ability to aid the formation of O_2 gas and its removal from the cell. Platinum is an especially desirable anode material. Nickel, copper and iron are less preferred because they tend to be less durable due to electrochemical reactions at the anode.

The method of the invention involves application of an electrical potential across the electrodes. Successful results have been obtained using DC power supplies providing from 3 to 25 volts across each cell at currents of from 10 to 500 mA. Correlations between fusion yield and voltage, current density, or surface characteristics of the metallic cathode have not yet been established.

Small jars, approximately 4 cm high x 4 cm diameter, holding approximately 20 ml of electrolyte solution each have been used as electrolytic cells. Such cells are very simple, and it is expected that further development will lead to improved cell designs.

Example

The reactor was comprised of a glass container holding a mixture of D_2O and H_2O with Na_2SO_4 (0.28 M) and H_2SO_4 as the supporting electrolyte. The volume of the solution was roughly 50 ml. The pH was near 3.8 at the end of the run. There was also dissolved iron in the solution. The cathode was a lump of spongy titanium (approximately 1 g, 75% voids) and the anode was gold foil. The applied voltage was approximately 10 V which resulted in a current of approximately 20 mA. Oxygen

bubbles formed immediately at the anode showing that electrochemical reactions were occurring at both electrodes. However, hydrogen bubbles did not appear at the cathode for several minutes. This indicates the hydrogen produced remained in intimate contact with the metal, and some may have been absorbed into the solid.

Fig. 3a shows background neutron counts as a function of neutron energy (channel number). Fig. 3b shows combined counts for deuteron loaded metals produced in three runs of electrolysis of water that was enriched in D_2O. Comparison of the figures clearly indicates the appearance of 2.5 MeV neutrons arising from nuclear d-d fusion. The excess counts shown in Fig. 3b in channels 40-130 indicate neutrons from d-d fusion were produced in the combined runs. The count rate in channels 40-130 is more than 2.5 times the background count rate. This represents seven times the standard deviation and is therefore highly significant statistically.

Loading catalytic materials: A number of pure metals, alloys, and compounds absorb hydrogen isotopes. The hydrogen may be dissolved or chemically bound in hydride form. In any case, there appear to be sites in the crystal lattice or at grain boundaries that catalyze nuclear fusion. Indirect evidence is provided by unusually high concentrations of ^3He (a d-d fusion product) in certain samples (e.g. nickel).

Figs. 4a and 4b schematically illustrate an arrangement for pressure loading a fusion fuel (e.g. D_2 or DT gas) into a catalyst metal sample 32 in a sample container 30. End caps 34 are provided to close off the container. The container itself may be formed of the catalytic material. Fuel gas (e.g. D_2) enters through inlet 36 and can be loaded through passageways 40 into the catalytic material at various pressures and temperatures, or it can be produced at the surface of the catalyst metal by electrolysis, or it could be loaded

into a solid catalyst material via ion implantation. An outlet 38 is provided for egress of unused fuel and ash (i.e. fusion product). The composition and the thermal and mechanical history of the catalyst are expected to affect the fusion rate, as is the operating environment. In this and other embodiments, the thickness and material of the container walls may be adjusted as desired to allow passage of the radiation, or adjusted to extract the maximum amount of radiation or energy from the fusion occurring inside. The fusion rate is controlled by the feed rate of the fuel. Higher rates may be obtainable by the use of external pressure (mechanical or hydraulic) and/or by temperature changes (heating or cooling).

A particular apparatus used to carry out pressure loading of fusion catalyzing material is illustrated in Fig. 5. The open end of a cylindrical stainless steel sample container 50 is connected via a cap 52 provided with an O-ring seal 53, a valve 54 and a coupling 56 to a manifold line 58 which leads to a vacuum pump 60. A control valve 62 is interposed between manifold 58 and vacuum pump 60. Manifold line 58 is also connected through a valve 64 to a high pressure source of hydrogen gas 66 provided with a pressure regulator 68 and through a valve 70 to a separate high pressure source of deuterium gas 72 which also is provided with a pressure regulator 74. A low pressure gauge 76 and valve 78 are provided to enable the system pressure to be monitored during evacuation by the vacuum pump 60. A high pressure gauge 80 and valve 82 are provided for monitoring the system pressure during gas infusion. The closed end of sample container 50 is adapted to be received in a high temperature furnace 84 with heating coils 86 which can produce controlled temperatures of up to 1000 °C. Such furnaces are commercially available.

A sample of metal 88 into which deuterium is to be infused is first inserted into the sample container 50,

and the container is then connected to the system and evacuated with the vacuum pump 60. The sample 88 is then heated to a temperature in the range from about 500 to 1000 °C, preferably about 600 to 800 °C, and evacuation is continued to remove adsorbed and absorbed gases. The pressure in the sample container is monitored, and heating and evacuation are continued until a stable low pressure condition is achieved indicating substantially complete outgassing of the sample. If desired, heating may be continued for a period of time after stable conditions have been achieved as a precautionary measure to assure complete removal of gasses from the sample. The vacuum pump is then valved off, and hydrogen and/or deuterium is admitted to the sample container. Gas pressures may be as high as the sample container can withstand. Effective results can be obtained with pressures in the range from 1 to 10 atmospheres, preferably about 4 to 7 atmospheres. Heating is then discontinued, and the sample is allowed to cool: Cooling may be passive, as by leaving the sample to cool to ambient temperatures, or it may be active, as by plunging the sample into liquid nitrogen or a refrigerated compartment. During heating and/or cooling, stresses and/or phase changes are generated in the sample which are believed to promote fusion of absorbed atoms in the metal sample. The sample is scanned for neutron and gamma emissions at the appropriate energies indicative of the occurrence of fusion.

Example

Strips of nickel foil approximately 3 mm wide and 12 cm long were buffed with aluminum oxide sanding paper to remove surface film. The strips were placed in a stainless steel sample tube, which was then sealed and connected to a pressure infusion apparatus corresponding to that illustrated in Fig. 5. The vacuum pump was

turned on and the furnace was energized. After approximately 1.5 hours, the furnace temperature gauge registered 670 °C and a secondary (Keithly) temperature gauge read 824 °C. The vacuum pump pressure gauge registered approx. 6μ $\eta\lambda$. The sample tube valve was closed to allow the vacuum pump to purge the system. Then the D_2 supply valve was opened to admit approx. 40 psi of deuterium gas. After closing off the D_2 supply and the sample tube, the system was again purged by the vacuum pump, and then the H_2 supply valve was opened to admit approx. 50 psi of hydrogen gas. The H_2 valve was closed and the sample tube valve opened to mix H_2 and D_2, and the furnace was turned off, leaving the sample tube connected to the manifold. The sample was allowed to cool under D_2 and H_2 pressure.

The deuterated nickel strip was placed next to a neutron spectrometer as shown in Fig. 1, and the emission of neutrons from the nickel strip was counted. The initial neutron count in spectrometer channels 100 to 250 was 6.27 $\pm$ 1.06 counts per hour which fell off over time to 5.18 $\pm$ .50 counts per hour and then to 4.68 $\pm$ .86 counts per hour. The background count in channels 100 to 250 was 4.96 $\pm$ .43 counts per hour. The neutron count in spectrometer channels 0 to 100 was 11.71 $\pm$ .75 counts per hour, and the background count in these channels was 8.10 $\pm$ 1.13 counts per hour. A repeat of the background for channels 0 to 100 gave 7.59 $\pm$ .53 counts per hour. Only background levels of neutrons were detected in spectrometer channels 250 to 511.

Codeposited catalysts: It may be possible to improve the structure of catalytic sites or increase their number per unit volume, or both, by codepositing the fuel and the catalytic material. Experimental evidence (see Figs. 3a and 3b) supports this notion. The fuel (e.g. hydrogen isotopes such as D_2) may serve as a template for the formation of the catalytic site.

Codeposition can be accomplished by condensation methods (e.g. evaporation, sputtering, chemical vapor deposition, ion implantation, etc.), or by electroplating, or by solidification of a melt or solution. The invention embraces methods for codepositing to form catalytic sites in films or bulk material of the proper shape and size for a fusion reactor. Fig. 6 schematically illustrates an electrolysis cell arrangement for codepositing fuel (e.g. deuterium) and catalytic material. Atoms and ions are shown greatly magnified. A pressure relief tube 26 is included to allow escape of gases produced during the electrolysis. Emissions of radiation and/or thermal energy may be produced during the deposition process.

Catalysis at particle surfaces: Small particles at least partly covered with isotopes of hydrogen may catalyze fusion. The hydrogen may be at interior sites in the particles. In any case, particle collisions would be expected to concentrate pressure at some of the sites and thus increase the fusion rate. Fig. 7 schematically illustrates an apparatus embodiment comprising a container 90 with catalytic particles 92 suspended inside, input means 94 for adding the fusion isotopes to the particles, and an ash output 96. Piezonuclear fusion is promoted by compression of fuel (e.g. deuterium) at the surfaces and in the interior of colliding moving particles. Thermal energy and radiation would be transmitted through the walls if the device is intended as a radiation source. As a power source, the walls would transmit only thermal energy. Particle size, composition, temperature, and background gas (if any) are important parameters for the control of fusion rate in this reactor. The particles may be produced by conventional methods (e.g. precipitation, condensation or grinding), or by other methods such as exploding wires.

Shocks in condensed matter: Shock waves created by impact, explosives, or electrical discharges create very

high transient pressures. Such shocks can be expected to increase the rate of nuclear fusion, especially for fuel in catalytic sites. Fig. 8 schematically illustrates an embodiment comprising a shaped condensed catalyst loaded with fuel, a mechanism for creating repeated shock waves in the catalyst, and a structure for transmitting or capturing the desired emission (radiation and/or thermal energy). The catalyst body 300 is shaped to concentrate the shock wave produced by the impact of a "hammer" 301 on an interposed anvil 302 which drives the catalyst body against a massive stationary anvil 303. The "hammer" may consist of material driven mechanically, explosively, or by electric discharge.

Detection Apparatus: The occurrence of cold nuclear fusion is confirmed by the detection of neutron emissions of the appropriate energy. For detection of neutron emissions which confirm the occurrence of piezonuclear fusion, e.g. during electrolytic infusion of isotopic hydrogen into the electrode, the electrolytic cells are placed on or alongside the neutron spectrometer 104 of Fig. 1.

As noted above, Fig. 1 schematically illustrates a particularly preferred neutron spectrometer adapted to register the 2.5 MeV neutrons produced from d-d fusion. Trimethylbenzene base liquid organic scintillator/moderator 112 (BC-505 from Bicron) is contained in the pyrex cylinder 108 having a diameter of about 12.5 cm, and in which three lithium-6-doped glass scintillator plates 120 are embedded. It is preferred to use a liquid scintillator based on trimethylbenzene because the trimethylbenzene has good neutron moderating ability and it also has an index of refraction near that of the ^{6}Li-glass. Another preferred liquid scintillator comprises decahydronaphthalene containing 4 grams per liter 2,5-diphenyloxazole and 0.5 g/l 1,4-bis-[2-(5-phenyloxazolyl)]-benzene. Suitable glass plates

containing approximately 57% SiO_2, 18% Al_2O_3, 17% Li_2O (95% ^6Li), 4% MgO and 4% Ce_2O_3 are commercially available from Levy West, Ltd., Harlow, London. Neutrons deposit energy in the liquid scintillator via collisions and the resulting light output yields energy information. These now low-energy neutrons are then scavenged by lithium-6 nuclei in the glass plates where the reaction n + ^6Li --> t + ^4He results in scintillations in the glass. Pulse shapes from the two media differ appreciably so that distinct signals are registered by the photomultiplier tubes (whose signals are summed). Due to the difference in pulse shapes, distinct signals from the two scintillation media can also be registered by the same photomultiplier tube, if desired. A coincidence of signals from the two media within 20 μsec identifies the neutrons.

The counting efficiency for the neutron detection system is of the order of 10%; that is to say, approximately one of every ten neutrons passing through the system will generate a detectable signal. Due to the fact that the detector is placed on only one side of the test cells, geometric considerations further reduce the effective counting efficiency by an additional factor of approximately 10%. Thus for every count detected in the illustrated experimental system in excess of background levels, approximately one hundred neutrons are generated in the experiment.

An overall wide-energy-spectrum calibration of the spectrometer may be obtained using neutrons from ^{252}Ca fission. Calibration with monoenergetic 2.9 and 5.2 MeV neutrons can be done with neutrons generated via deuteron-deuteron interactions at 90° and 0°, respectively, with respect to the deuteron beam from a Van de Graaff accelerator. The observed energy spectra show a broad structure which implies that 2.45 MeV neutrons should appear in the multi-channel analyzer

spectrum in channels 45 to 150. Stability of the detector system can be checked between data runs by measuring the counting rate for fission neutrons from a broad-spectrum californium-252 source. We have performed other extensive tests proving that our neutron counter does not respond preferentially in this pulse height range to other sources of radiation, such as thermal neutrons.

Background rates in the neutron counter are approximately 10^{-3} s^{-1} in the energy region where 2.5 MeV neutrons are anticipated. By comparing energy spectra from gamma and neutron sources we have determined that approximately three-fourths of the background comes from thermal neutrons of cosmic ray origin and the remainder of the background stems from accidental coincidences of gamma-ray events. Improvements in shielding and gamma-ray signal detection and rejection were pursued throughout the experiments, resulting in a significant reduction in background levels.

A schematic representation of the electronic circuitry used in the neutron detector is illustrated in Figs. 9a and 9b. The electronic system which processes the signals taken from the neutron detector 104 is governed by the logic requirement that only liquid event pulses which fall within a preselected gate time prior to a pulse identified as a neutron capture event are actually counted and measured. Thus, the conditioning electronics is sensitive to the total energy of the neutron resulting in two characteristic pulses of light occurring within a predetermined coincidence time. The coincidence requirement is designed to reduce background counts resulting from gamma rays to which the liquid scintillator 112 is also sensitive. Thus, the electronics, through pulse-shape discrimination, is able to distinguish a glass-produced light event, having a relatively long delay time of about 70 nsec, from a

liquid-produced event having a relatively short decay time of about 5 nsec.

Each of the photomultiplier tubes 110a and 110b produces an anode and a dynode signal. As shown in Fig. 9a, the A-anode signal from photomultiplier tube 110a is fed to an integrating amplifier 200a whereas the B-anode signal from photomultiplier tube 110b is fed to an integrating amplifier 200b. Integrating amplifiers 200a and 200b may, for example, be stretcher amplifiers AN105 supplied by EG&G. These amplifiers have been coupled to grounding switches to enhance integration time characteristics as will be explained hereinbelow. The outputs of integrating amplifiers 200a and 200b are fed to a summer 202 and the summed output is supplied to an amplifier 204 which may, for example, be an ORTEC linear amplifier model 572. The output of amplifier 204 is fed to a delay amplifier 206, as, for example, a series of ORTEC 427A units. The delay amplifier 206 supplies a 20 microsecond delay and subsequently feeds the signal to an analog to digital (A/D) converter 210. The output of the A/D converter is fed to a pulse height analyzer 212. The A/D converter 210 performs the digital conversion of the incoming analog signal from the delay amplifier 206 only upon receipt of a gating or coincidence signal fed to a coincidence input terminal 214.

The output of summer 202 is also fed to a gate 220, as, for example, a linear gate LG101 supplied by EG&G. The output of gate 220 is fed to a shaper/amplifier 222 such as an ORTEC time filter amplifier model 454. The output of the shaper/amplifier 222 is in turn fed to a discriminator 224 coupled with a delay 225 of a 10 nsec period to supply a narrow output logic pulse signal to a pulse stretcher 226. The discriminator 224 may be, for example, EG&G model T101 and the pulse stretcher 226 may be EG&G model GG100. The output of the pulse stretcher 226 is fed to a linear gate 230 via a 10 db attenuator,

not shown. Linear gate 230 may, for example, be a logic gate and slow coincidence module supplied by ORTEC as model 409. The output of linear gate 230 is in turn fed as a coincidence signal to the coincidence input terminal 214 of A/D converter 210.

In reference to Fig. 9b, the A and B dynode outputs of photomultiplier tubes 110a and 110b respectively are fed to a summer 240 which provides a summed output to amplifier 242 which may be, for example, an ORTEC timing filter amplifier model 454. The output of the amplifier 242 is split by a three-way coupler 244 and fed to a differential discriminator 246 coupled to a 118 nsec delay 248. The differential discriminator 246 may, for example, be EG&G model TD101/N. The output of the differential discriminator 246 is fed to a gate and delay circuit 250 such as, for example, ORTEC model 416A. The output of gate and delay 250 supplies a signal along line G1 as the gating input signal to gate 220 of Fig. 9a.

The second output of three-way coupler 244 is fed to another differential discriminator 252, such as, for example, EG&G model TD101/N. The output of this differential discriminator 252 is fed to a gate and delay circuit 254, such as ORTEC model 416. The output of gate and delay circuit 254 is fed by a signal line G2 to an anti-coincidence input terminal of gate 230.

The summed output of summer 240 is also fed to an amplifier 260 which may be, for example, EG&G model AN101. The output of amplifier 260 is in turn fed to a gate generator 262 which is coupled to a 400 nsec delay 264. The gate generator 262 may, for example, be an EG&G model T101 discriminator. The output of the gate generator 262 is fed to a grounding switch 268a and to an identical grounding switch 268b. Grounding switch 268a supplies an output along signal line SW A to a conditioning input of integrating amplifier 200a. Similarly, the output of grounding switch 268b supplies a

signal along signal line SW B as a conditioning signal to integrating amplifier 200b.

Normally conductive matched diodes within the grounding switch provide a low impedance path to ground permitting a relative fast RC integrating time constant. Upon application of the 400 nsec gate signal from the gate generator 262, the switch becomes non-conductive for a set period of time (~ 400 nsec) thereby providing a high impedance path through the (R3)(C) (R3=100K ohm) path of the integrating amplifier 200a thus producing a relatively long integrating time on the order of 300 μs. The ground switch is also shown in Figure 2 of the article entitled "A New Technique for Capture and Fission Cross-Sectioned Measurements" appearing in Nuclear Instruments and Methods, Volume 72, pages 23-28, 1969, by J. B. Czirr, incorporated herein by reference.

In operation, the block diagram of Figs. 9a and 9b is seen to contain a first branch (Fig. 9a) which may be termed the "total light" branch and a second branch (Fig. 9b) which may be termed the "early light" branch. In the "total light" branch of Fig. 9a, the incoming light signal is fully integrated in integrating amplifiers 200a and 200b. The outputs of integrating amplifier 200a and 200b are summed in the summer 202 and subsequently amplified in amplifier 204 which also provides pulse shaping. The shaped output of amplifier 204 is delayed by a delayed amplifier 206 which provides a 20 microsecond delay prior to feeding the analog signal to the A/D converter 210. If the coincidence signal is present at the coincidence input terminal 214 of the A/D converter 210, the digital conversion takes place, and the digitized output signal is fed to the pulse height analyzer 212 thereby providing a measure of the total light energy supplied to the photomultiplier tube. This total light output is proportional to the integrated output from the light pulses produced by the incident

neutron in the liquid scintillator-moderator 112. Since the light pulse produced by thermal neutrons in the glass scintillator plates 120 is constant, it need not be stored in the pulse height analyzer. Thus, the glass event is not gated into the A/D converter 210 so it never gets digitized. Thus, a measure of the integrated light output produced in the liquid scintillator during the thermalizing of the incident neutron provides complete information as to the incident neutron energy.

The gating signal supplied to the coincidence input terminal 214 of the A/D converter 210 is generated from a second branch of the summer 202. This second branch is shown by the lower branch in Fig. 9a and comprises the gate 220, shaper/ amplifier 222, discriminator 224, pulse stretcher 226 and linear gate 230. The purpose of the above-mentioned circuits, together with certain elements of Fig. 9b, is to determine whether the incoming light was produced from the liquid scintillator-moderator 112 or from the glass scintillator 120. Inasmuch as it is only desired to store data about light from the liquid scintillator 112 if it is followed within a predetermined time period (20 microseconds) by a characteristic neutron capture event from the glass scintillator 120, the initial signal generated from the liquid scintillator 112 is delayed in the delay amplifier 206 to permit sufficient analysis time for the subsequently generated signal produced in the glass scintillator 120.

Fig. 9b shows the "early light" branch which is also utilized to differentiate between light generated in the liquid scintillator-moderator 112 and the glass scintillator 120. Elements at 242, 244, 246, 248 and 250 are utilized to select, through pulse-shape discrimination and amplitude criteria, only those events which correspond to neutron capture in the glass scintillator 120. The output of the summer 240 is fed to the amplifier 242 which is operated with a fast

integration time of 50 nsec. The term "early light" is used to characterize this branch (Fig. 9b) since the integration time of amplifier 242 is much shorter than that of amplifier 200a and 200b. The output of amplifier 242 is then fed via the three-way coupler 244 to the differential discriminator 246. This differential discriminator 246 selects a region in the pulse height of the incoming signal corresponding to glass events which have an intensity corresponding to neutron capture in the Li-6. Gamma ray background events will also fall within the selected pulse height window. However, the "total light" from these gammas will be considerably less than that from neutron capture in the glass because of the relatively longer decay time of the neutrons in the glass. Thus, even though indications of such gamma events will pass through differential discriminator 246 and gate and delay circuit 250 so as to trigger the linear gate 220 (Fig. 9a), they will be eliminated by means of the discriminator 224 which selects only a certain upper energy spectrum from the "total light" spectrum input thereto.

The data processing logic of Figs. 9a and 9b also eliminates successive signals resulting from successive neutron captures in the glass. Such events are eliminated by means of the differential discriminator 252 (set at about the same window as differential discriminator 246) and gate and delay circuit 254 supplying an anti-coincidence signal along line G2 to the anti-coincidence input of gate 230. For example, the first neutron capture event in the glass scintillator 120 passes through differential discriminator 252 and produces the anti-coincidence signal via gate and delay circuit 254. Likewise, this same first signal passes through the differential discriminator 246 enables gate 220 and passes the first signal through the discriminator 224 and pulse stretcher 226. As such, the anti-

coincidence signal G2 is fed into the linear gate 230 together with the coincidence signal from the pulse stretcher 226 thereby preventing any coincidence signal from being generated and fed to the A/D converter 210. Upon receipt of the second signal, again the anti-coincidence signal is generated at the linear gate 230 thereby blocking the delayed first signal from the delay 206 from being digitized by the A/D converter 210.

An alternate anti-coincidence circuit for eliminating successive neutron capture events in the glass may be implemented by passing the output of the discriminator 224 to a gate and delay circuit 280 (Fig. 9a) similar to the gate and delay circuit 254. The output of the gate and delay circuit 280 is in turn fed as the signal along line G2 to the anti-coincidence terminal of linear gate 230.

Further details of the operation of the electronics and the detector circuitry may be found in commonly assigned copending application by John Bartley Czirr et al. entitled "Neutron Coincidence Calorimeter" filed April 25, 1989. (Attorney Docket No. 30251/102 BRYU), which is incorporated herein by reference.

In addition, there is indication of 5.4 MeV gamma rays in a standard 3" NaI detector. A 32 x 32 x 1.25 cm scintillation counter is used to veto cosmic ray background noise. Background counts are low and stable from day to day.

Fig. 10 displays the neutron energy spectrum obtained under conditions described above, juxtaposed with the background spectrum. In the figure, foreground (solid) and background (dotted) counts are shown as functions of pulse height in the neutron spectrometer, and ten counts have been added to each three-channel bin for clarity of presentation.

Assuming conservatively that all deviations from background are statistical fluctuations, the background

counts are scaled by a factor 0.46 to match the foreground counts over the entire energy range (channels 0 to 511) illustrated in the figure. A feature in channels 45-150 still rises above background by nearly four standard deviations. This implies that our assumption is too conservative and that this structure represents a real physical effect.

Fig. 11 is a difference spectrum obtained by subtracting scaled background from the foreground. Statistical errors are shown. The illustrated plot of the difference between the foreground and background levels was obtained by rescaling the background by a factor of 0.44 to match the foreground level in regions just above and just below the feature in channels 45 to 150. It shows a robust signal centered at channel 100 of over five standard-deviation statistical significance. A Gaussian fit to this peak yields a centroid at channel 101 and a sigma of 28 channels. This is precisely where 2.5 MeV fusion neutrons should appear in the spectrum. The fact that a significant signal appears above background with the correct energy for d-d fusion neutrons (~2.5 MeV) provides strong evidence that room temperature nuclear fusion is indeed occurring in the electrolytic catalysis cells.

Tests 1 - 14:

Fig. 12 depicts the ratio of foreground rate to background rate in the 2.5 MeV-energy region of the pulse-height spectrum for fourteen individual test runs which enter into the combined data discussed above. Fig. 12 displays, for each run, the ratio of foreground count rate in the 2.5 MeV-energy region with background rates obtained for each run. Background rates were improved upon during the experiments, so we plot the data in terms of foreground-to-background ratios rather than absolute rates.

Run 6 is particularly noteworthy, having a statistical significance of approximately 5 standard deviations above background. Fused titanium pellets were used as negative electrodes with a total mass of about 3 g. The neutron production rate increased after about one hour of electrolysis. After about eight hours, the rate dropped dramatically as shown in the subsequent run 7. At this time, surfaces of the Ti electrodes showed a dark gray coating. An analysis using electron microscopy with a microprobe showed that the surface coating was mostly iron, deposited with deuterons at the cathode.

The same phenomenon of having the neutron signal drop after about eight hours of operations appears in run 13 followed by run 14. Runs 13 and 14 use the same eight electrochemical cells, and again the negative electrodes developed coatings after a few hours of electrolysis. These observations suggest the importance of surface conditions on the cold fusion process. Wide variations in surface conditions are anticipated in operating electrochemical cells with numerous ionic species, and these variations may account for the fluctuations in the signal level which are evident in Fig. 12. In particular, the observed "turning off" of the signal after ~8 hours may account for a low signal-to-background ratio in runs 1 and 3, in that a few-hour signal may have been overwhelmed after a long (~20 hour) running time. No separate observations were made of the first few hours of these runs.

When run 10 started with rates substantially above background, we stopped the run and removed half of the electrochemical cells as a test. The neutron production rate dropped off as expected (run 11). In determining the statistical significance of the data, we included runs 1, 3, 7, 11 and 13, even though we see a systematic reason for their low-foreground-to-background ratios as explained above. Run 8, shown in Fig. 12, was

inadvertently lost from the magnetic storage device and could not be included in Figs. 10 and 11. This does not change our conclusion.

Extensive efforts were made to generate false neutron signals by using various gamma and neutron sources. We also turned auxiliary equipment on and off; the Van de Graaff accelerators were kept off. The signals persisted as shielding was moved and as electronics modules were tuned. Background runs taken using operating electrochemical cells similar to those described above but with H_2O replacing D_2O were featureless. No net counts above background were observed when the standard cells were used with no current flowing.

The cold nuclear fusion rate during electrolytic fusion is estimated specifically for run 5 (Fig. 12) as follows:

$$\text{Fusion per deuteron pair} = \frac{R}{\epsilon} \; / \; M \times \frac{d}{2M} \qquad (2)$$

where the observed fusion rate $R = (4.1 \pm 0.8) \times 10^{-3}$ fusion/s; the neutron detection efficiency, including geometrical acceptance, is calculated using a Monte Carlo neutron-photon transport code [see MCMP:Monte Carlo Neutron and Photon Transport Code, CCC-200; available from Radiation Shielding Information Center, Oak Ridge National Laboratory (Version 3)] to be $\epsilon = (1.0 \pm 0.3)\%$; where $M \simeq 4 \times 10^{22}$ titanium atoms for 3 g of titanium; and the deuteron-pair per metal ion ratio

$\frac{d}{2M} \approx 1$ is based on the assumption that nearly all tetrahedral sites in the titanium lattice are occupied, forming the γ-TiD_2 hydride. Then the estimated cold nuclear fusion rate by equation (2) is

$$\lambda_f \sim 10^{-23} \text{ fusion/deuteron pair/second.} \qquad (3)$$

If most fusions take place near the surface or if the titanium lattice is far from saturated with deuterons, or if conditions favoring fusions occur intermittently, then the inferred fusion rate must be much larger, perhaps 10^{-20} fusions/d-d pair/second. Such a fusion rate could be achieved by "squeezing" the deuterons to half their normal (0.74 Å) separation in molecules. That such rates are now observed in condensed matter suggests "piezonuclear" fusion as the explanation [Van Siclen et al., op cit.]. A possible cause is that quasi-electrons form in the deuterated metal lattice having an effective mass a few times that of a free electron. Isotopic hydrogen is known to accumulate at imperfections in metal lattices [Bowman, Metal Hydrides (ed. G. Bambakides) 109-144 (New York, Plenum, 1981).] and local high concentration of hydrogen ions might be conducive to piezonuclear fusion.

The absence of observations of fusion in equilibrated, deuterated metals or compounds such as methylamine-d_2 deuteriochloride or ammonium-d_4 chloride, suggests that non-equilibrium conditions are advantageous. Electrolysis is one way to produce conditions which are far from equilibrium. Other procedures which may be used to generate fusion promoting non-equilibrium conditions or stress include subjecting the infused sample to variations in pressure, temperature, phase, mechanical shocks, etc. Such non-equilibrium conditions are believed to promote stress induced hopping of ions which favors the occurrence of fusion.

The rate of emission of radiation (primarily neutrons and gamma rays) is generally proportional to the level of the operating parameters. In electrolytic embodiments, voltage and current density probably have the strongest influence on the rate, at least up to some saturating voltage. In any case, the radiation can be

turned on or off or run at some intermediate level with transition times depending on the rate of fusion at loaded catalytic sites or the rate of refilling sites with existing fuel. This control of the level during continuous operation confers an important advantage.

It can therefore be seen that the present invention provides a new method of promoting cold nuclear fusion through infusion of deuterons into materials such as metals. While the need for off-equilibrium conditions is clearly implied by our data, techniques other than electrochemical may also be successful. Metals, which had been outgassed by heating to high temperatures (600 to 800 °C) under vacuum, have been infused with deuterium by subjecting the hot metal to deuterium at elevated pressure (≥4 atmospheres), and then the metals were subsequently cooled under D_2 gas pressure to induce fusion. The results were comparable to those obtained using electrolytic infusion into metals. Fusion may also be promoted by heating deuterium infused samples. If desired, sample preparation (e.g. outgassing of samples) may be effected under an inert atmosphere rather than under vacuum. We have begun to explore the use of ion implantation, and of elevated pressures and temperatures.

If deuteron-deuteron fusion can be catalyzed, then the d-t fusion reaction is probably favored due to its larger nuclear cross section. Thus, while the fusion rates observed so far are small, the discovery of cold nuclear fusion in condensed matter opens the possibility, at least, of a new path to fusion energy.

The invention may find application in any of the following uses:

Nondestructive testing: The radiation from the invention can be used to image the interiors of opaque objects, and thus to detect flaws or structures of interest. Examples are the searching of airline baggage for plastic or other explosives; the examination of

aircraft wings and other structures for flaws in the internal honeycomb; detection of imperfections in welds of all kinds; and measurement of flow rate and impurities in oil pipelines.

Promotion of chemical and nuclear reactions: Hot atom chemistry resulting from ionizing radiation produces products that are often not obtainable by conventional methods. In addition, such radiation kills microorganisms and can be used in preserving food, etc. Radiation crosslinks certain types of polymers and improves their mechanical properties. Certain chemical elements are transmuted to other (more valuable) elements upon absorption of a neutron. An example is ^{196}Hg to gold. The invention may also be used to generate helium and tritium.

Elemental analysis: The envisioned radiation sources can be used to stimulate x-ray fluorescence that is of value in elemental analysis. With some elements, the neutrons cause neutron activation with subsequent emission of radiation characteristic of the activated element.

Power production: Thermal energy and charged particles are produced by nuclear fusion reactions. In sufficient amounts, such thermal energy can be used for space heating, running heat engines, producing electrical power (e.g with steam turbines) or even direct conversion of the flux of charged particles directly into electrical power.

Particular advantages of the invention include: 1) use of reactors that are small, inexpensive, and operate at temperatures much lower than conventional plasma fusion reactors; 2) use of catalysis rather than thermal energy to overcome the coulomb barrier; 3) control of the rate of fusion at far lower rates than in conventional methods which have high thresholds of energy input before fusion starts; 4) continuous operation as compared to

conventional methods which emit short pulses of energy that are difficult to harvest and require special containers to prevent damage to the reactor; 5) operation at easily accessible pressures (some embodiments at ambient pressure) as contrasted with most conventional methods which require vacuum chambers; and 6) elimination of any need for large, expensive particle accelerators to produce catalytic particles such as muons.

As used herein the term "enriched content of fusionable nuclei" refers to fusionable nuclei contents in excess of naturally occurring levels. Statements that a phenomenon occurs "at" the electrode are intended to include occurrences both at the surface of the electrode and within the electrode.

The foregoing description has been set forth merely to illustrate the invention and is not intended to be limiting. Since modifications of the described preferred embodiments which incorporate the spirit and substance of the invention may occur to persons skilled in the art, the scope of the invention should be construed solely with reference to the appended claims and equivalents thereof.

What Is Claimed Is:

1. A method of fusing nuclei together comprising the steps of infusing fusible nuclei into a host electrode by causing an electric current to pass through said host electrode in contact with an electrolyte containing said fusible nuclei.

2. A method of inducing nuclear fusion comprising the steps of:

a) exposing at least a part of a host electrode to an electrolyte containing nuclei to be used in a nuclear fusion process,

b) passing an electric current through said host electrode and electrolyte to cause infusion of said nuclei on or within said host electrode, and

c) maintaining current through said host electrode and electrolyte for a period of time sufficient to induce said nuclear fusion process.

3. A method of causing a nuclear fusion process comprising the steps of infusing nuclei used in said fusion process into a host absorbing material for a time sufficient to produce said nuclear fusion process, said infusion catalyzed by passing an electric current between said host absorbing material and said nuclei.

4. A method of promoting nuclear fusion comprising the steps of:

- contacting an electrode of hydrogen absorbing, electrically conductive material and a counterelectrode with a deuterium enriched electrolyte; and
- applying an effective fusion promoting negative electrical potential to said electrode with reference to said counterelectrode for a period of time sufficient to induce nuclear fusion of deuterium at said electrode.

5. A method according to Claim 4, wherein said electrode is formed of titanium.

6. A method according to Claim 4, wherein said electrode is formed of palladium.

7. A method according to Claim 4, wherein said counterelectrode is formed of gold.

8. A method according to Claim 4, wherein a negative DC potential in the range from 3 to 25 volts is applied to said electrode with reference to said counterelectrode.

9. A method according to Claim 4, wherein said electrolyte comprises at least 90 weight percent deuterium oxide.

10. A method according to Claim 4, wherein said electrolyte is aqueous and comprises from 0.001 to 0.5 weight percent of at least one soluble salt of a metal selected from the group consisting of iron, nickel, palladium, calcium, lithium, sodium, titanium and gold.

11. A method according to Claim 4, wherein said electrolyte is aqueous and comprises from 0.001 to 0.5 weight percent of at least one salt selected from the group consisting of iron sulfate, nickel chloride, palladium chloride, calcium carbonate, lithium sulfate, sodium sulfate, calcium hydrogen phosphate, titanium oxysulfate and gold cyanide.

12. A method according to Claim 4, wherein said electrolyte is aqueous and has a pH of at most about 3.

13. A method according to Claim 4, wherein said electrode and said counterelectrode are spaced from 1 to 50 millimeters apart.

14. A method according to Claim 4, wherein said method is carried out at a temperature in the range from 15 to 100 °C.

15. A method according to Claim 4, wherein said method is carried out at ambient temperature and pressure.

16. A method according to Claim 4, wherein said electrode is formed of a material selected from the group consisting of lanthanum, nickel, iron, copper, zirconium, tantalum, and lithium-aluminum hydride.

17. A method according to Claim 4, wherein an electrical current in the range from 10 to 500 milliamps is passed between said electrode and counterelectrode.

18. A method of promoting nuclear fusion comprising contacting both an electrode of hydrogen absorbing, electrically conductive material and a counterelectrode with an aqueous electrolyte having an enriched deuterium content, and applying an electrical potential between said electrode and counterelectrode to produce a region of increased deuterium concentration at said electrode in which the equilibrium separation between deuterons is less than 0.74 Angstroms;

whereby fusion of deuterium occurs at said electrode.

19. A method according to Claim 18, wherein neutrons are emitted from said electrode or from said electrolyte as a result of the deuterium fusion, further comprising the step of capturing emitted neutrons and producing a signal proportional to the rate of neutron capture, said signal

indicating the rate of deuterium fusion occurring at said electrode.

20. A method of infusing hydrogen into a metal comprising the steps of contacting an electrode of said metal with a deuterium enriched aqueous electrolyte and applying a negative electrical potential with reference to a counterelectrode in contact with said electrolyte sufficient to infuse deuterium into said metal electrode.

21. A method according to Claim 20, wherein said metal electrode is copper.

22. A method according to Claim 20, wherein said electrolyte is a hydrogen chloride solution.

23. A method according to Claim 20, wherein said counterelectrode is a nickel anode.

24. A method according to Claim 20, wherein said electrical potential is applied for a period of at least 8 hours.

25. A method according to Claim 20, wherein said electrical potential is 1.5 volts.

26. A method according to Claim 20, wherein said counterelectrode is a copper anode.

27. A method according to Claim 20, wherein said electrolyte is a sulfuric acid solution.

28. A method according to Claim 20, wherein said electrode is a palladium cathode.

29. A method according to Claim 20, further comprising the step of monitoring the emission of neutrons from said electrode during the application of said electrical potential.

30. A method of promoting nuclear fusion comprising the steps of contacting an electrode of a material selected from the group consisting of palladium, lithium, aluminum, copper, nickel and platinum with an electrolyte having an enriched content of fusionable nuclei and applying an effective fusion promoting negative electrical potential to said electrode with reference to a counterelectrode in electrical contact with said electrolyte for a period of time sufficient for fusion of said nuclei to occur.

31. A method according to Claim 30, wherein said electrolyte is a deuterium oxide solution.

32. A method of promoting nuclear fusion comprising the steps of distorting internuclear wave functions of a given nuclei by loading said given nuclei into a host material thereby increasing the probability of nuclear fusion of said given nuclei above that of non-loaded nuclei.

33. A method as recited in claim 32, wherein said given nuclei comprise hydrogen.

34. A method as recited in claim 32, wherein said given nuclei comprise an isotope of hydrogen.

35. A method of promoting nuclear fusion comprising the step of loading given nuclei into a host material in sufficient amounts so as to cause nuclear fusion of said nuclei.

36. A method as recited in claim 35, wherein said given nuclei comprise hydrogen or a hydrogen isotope.

37. A method of producing heat comprising the step of loading given nuclei into a host material in sufficient amounts so as to cause nuclear fusion of said nuclei.

38. A method as recited in claim 37, wherein said given nuclei comprise hydrogen or a hydrogen isotope.

39. A method of producing helium comprising the steps of loading deuterons into a host material in sufficient amounts so as to cause nuclear fusion of said nuclei.

40. A method as recited in claim 39, wherein said host material comprises a hydrogen-absorbing material.

41. A method as recited in claim 39, wherein said host material comprises titanium.

42. A method as recited in claim 39, wherein said host material comprises palladium.

43. A method of producing tritium comprising the step of loading deuterons into a host material in sufficient amounts so as to cause nuclear fusion of said deuterons.

44. A method as recited in any one of claims 32, 35, 37, 39, or 43, wherein said loading step includes the step of subjecting said nuclei and host material to electrolysis, wherein said host material forms an electrode and said nuclei are contained within an electrolyte.

45. A method as recited in any one of claims 32, 35, 37, 39, or 43, wherein said loading step includes the step of subjecting said nuclei and host material to pressure.

46. A method as recited in any one of claims 32, 35, 37, 39, or 43, wherein said loading step includes the step of subjecting said host material to a gas containing said nuclei and applying pressure to said gas.

47. A method of infusing nuclei into a host material comprising the steps of:

a) heating said host material under vacuum to outgas said host material, and

b) impregnating said host material with fusible nuclei by:

1) cooling or heating said host material, and

2) simultaneously exposing said host material to a gas under pressure, said gas containing said nuclei.

48. A method as recited in claim 47 wherein said gas comprises hydrogen or an isotope thereof.

49. A method of promoting nuclear fusion comprising the steps of:

a) heating a host material under vacuum to outgas said host material, and

b) impregnating said host material with fusible nuclei by:

1) cooling or heating said host material, and

2) simultaneously exposing said host material to a gas under pressure, said gas containing said nuclei.

50. A method of generating a nuclear fusion reaction comprising the step of impregnating fusible nuclei into a host material in sufficient amounts to promote a nuclear fusion reaction involving said fusible nuclei.

51. A method as recited in claim 50 further including the step of measuring the energy of a fusion reaction product produced in said fusion reaction.

52. A method of causing a nuclear fusion reaction comprising the steps of:

a) heating a host material to outgas said host material,

b) impregnating said host material with at least one group of nuclei to be used in said fusion reaction, and

c) catalyzing said fusion reaction by cooling or heating said impregnated host material.

53. A method of promoting nuclear fusion comprising the steps of:

a) exposing at least a part of a host electrode to an electrolyte containing nuclei to be used in a nuclear fusion process,

b) passing an electric current through said host electrode and electrolyte to cause infusion of said nuclei on or within said host electrode,

c) depositing additional material onto said host electrode, said deposited additional material being other than said nuclei, and

d) maintaining current through said host electrode and electrolyte for a period of time sufficient to cause said nuclear fusion process.

54. Apparatus for inducing nuclear fusion comprising:

a) means for exposing at least a part of a host electrode to an electrolyte containing nuclei to be used in a nuclear fusion process,

b) means for passing an electric current through

said host electrode and electrolyte to cause infusion of said nuclei on or within said host electrode, and

c) means for maintaining current through said host electrode and electrolyte for a period of time sufficient to cause said nuclear fusion process.

55. Apparatus for promoting nuclear fusion comprising:

- means for contacting an electrode of hydrogen absorbing, electrically conductive material and a counterelectrode with a deuterium enriched electrolyte; and

- means for applying an effective fusion promoting negative electrical potential to said electrode with reference to said counterelectrode for a period of time sufficient to induce nuclear fusion of deuterium at said electrode.

56. Apparatus for infusing nuclei into a host material comprising:

a) means for heating said host material under vacuum to outgas said host material, and

b) means for impregnating said host material with fusible nuclei including:

1) means for cooling or heating said host material, and

2) means for simultaneously exposing said host material to a gas under pressure, said gas containing said nuclei.

57. Apparatus for promoting nuclear fusion comprising:

a) means for heating a host material under vacuum to outgas said host material, and

b) means for impregnating said host material with fusible nuclei including:

1) means for cooling or heating said host material, and

2) means for simultaneously exposing said host material to a gas under pressure, said gas containing said nuclei.

58. Apparatus for generating neutrons comprising means for impregnating fusible nuclei into a host material in sufficient amounts so as to promote nuclear fusion reactions involving said fusible nuclei, said nuclear fusion reactions producing neutrons, and means for detecting said neutrons.

59. Apparatus for causing a nuclear fusion reaction comprising:

a) means for heating a host material to outgas said host material,

b) means for impregnating said host material with at least one group of nuclei to be used in said fusion reaction, and

c) means for catalyzing said fusion reaction by cooling or heating said impregnated host material.

60. Apparatus for promoting nuclear fusion comprising:

a) means for exposing at least a part of a host electrode to an electrolyte containing nuclei to be used in a nuclear fusion process,

b) means for passing an electric current through said host electrode and electrolyte to cause infusion of said nuclei on or within said host electrode,

c) means for depositing additional material onto said host electrode, said deposited additional material being other than said nuclei, and

d) means for maintaining current through said host electrode and electrolyte for a period of time sufficient to cause said nuclear fusion process.

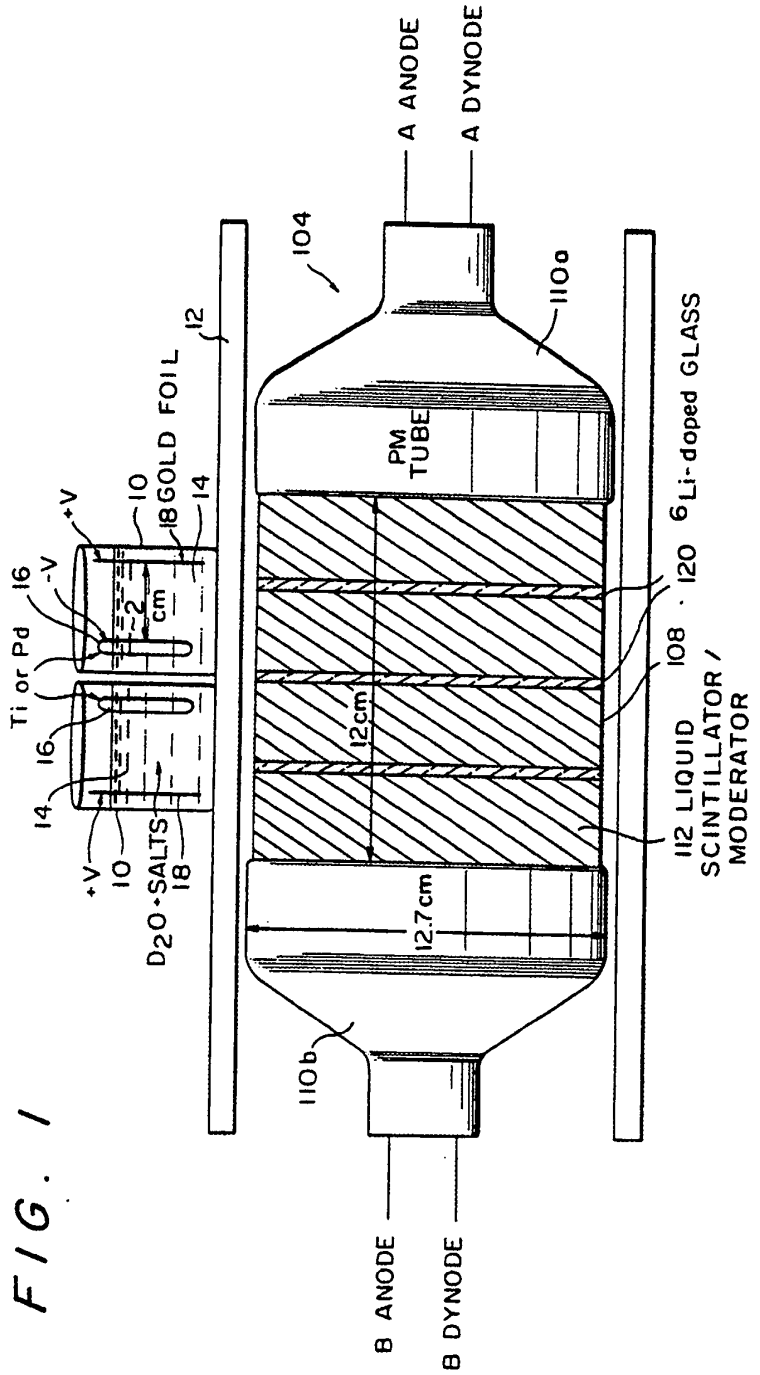

A ANODE
A DYNODE
104
110a
12
PM TUBE
6Li-doped GLASS
120
108
112 LIQUID SCINTILLATOR / MODERATOR
12cm
12.7cm
110b
B ANODE
B DYNODE
GOLD FOIL
10
18
14
16
+V
-V
2 cm
Ti or Pd
D2O+SALTS

FIG. 1

FIG. 2

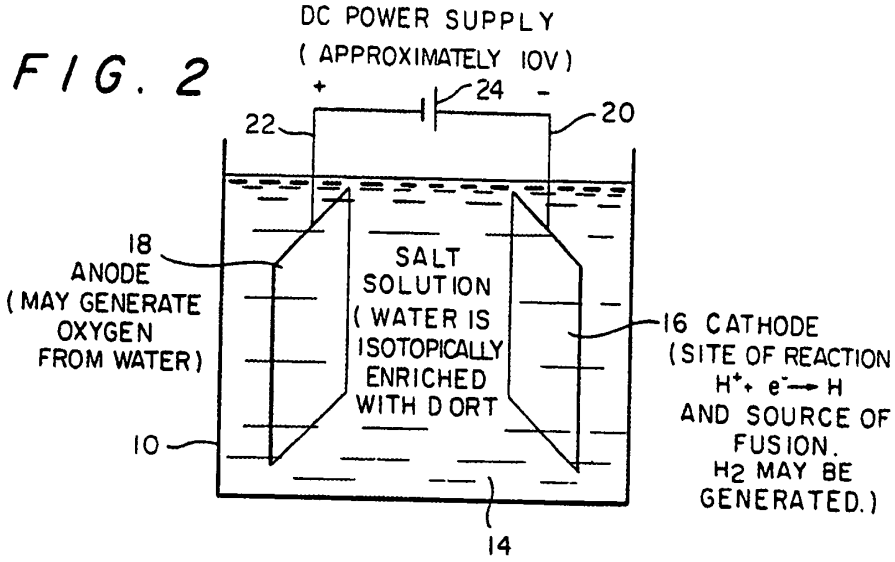


FIG. 4A

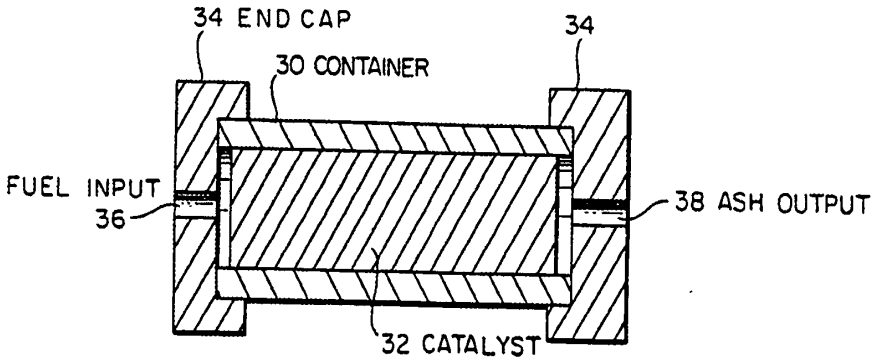


FIG. 4B

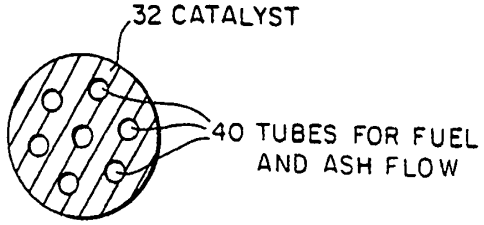


FIG. 3a

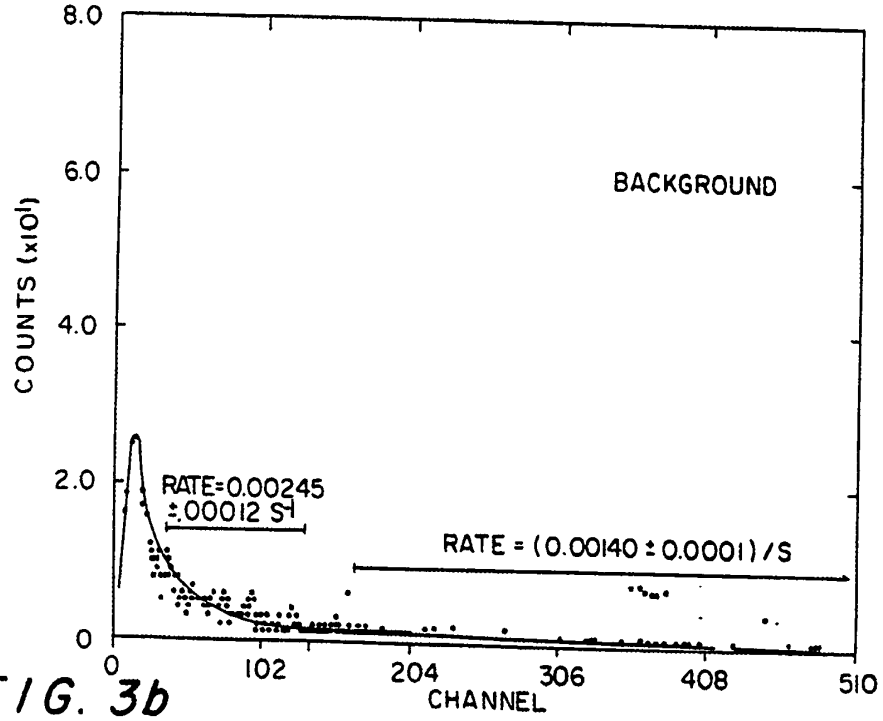
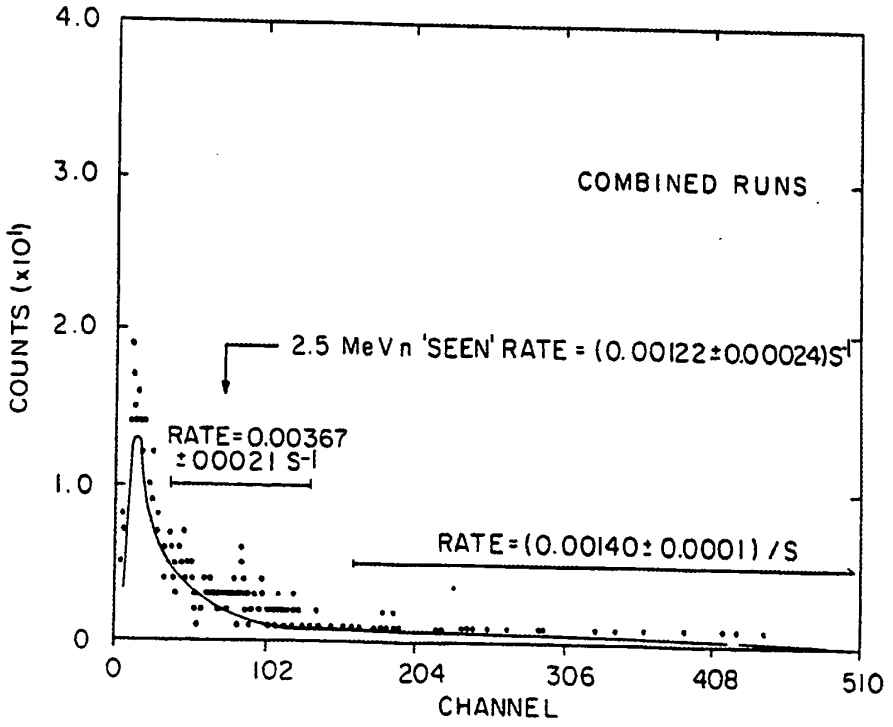
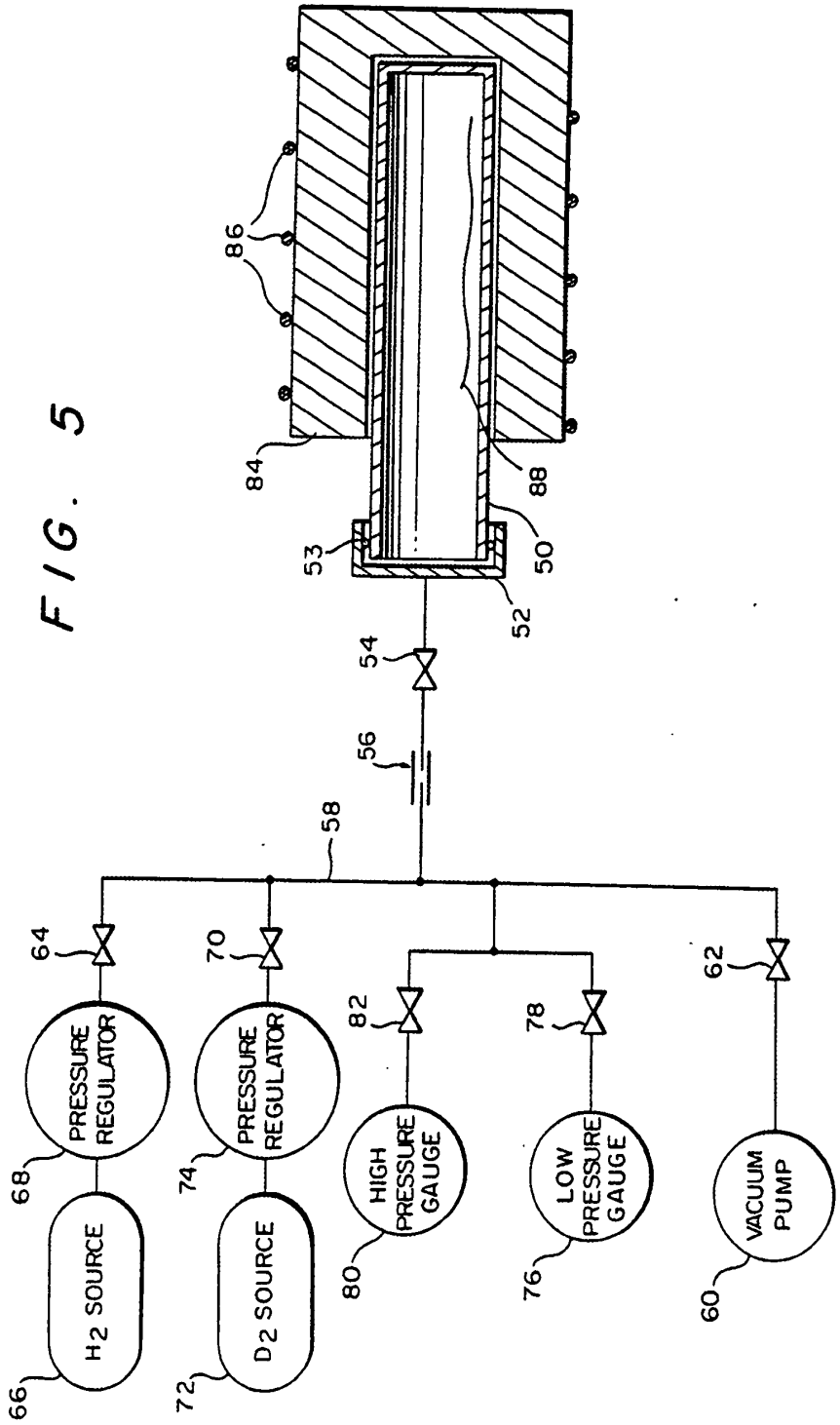


FIG. 3b



4/3/06, EAST Version: 2.0.3.0

FIG. 5



4/3/06, EAST Version: 2.0.3.0

FIG. 6

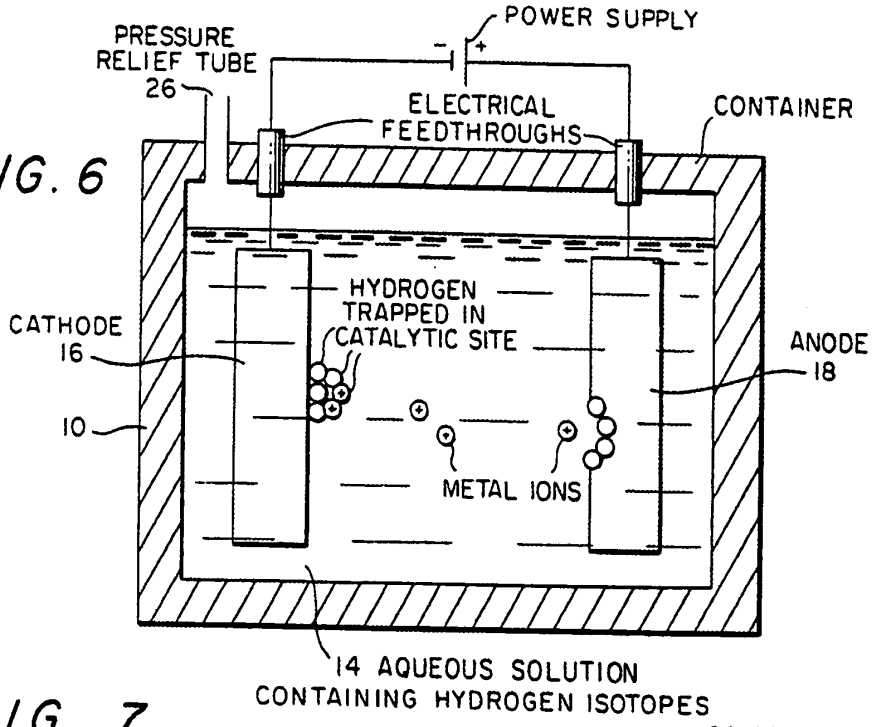


FIG. 7

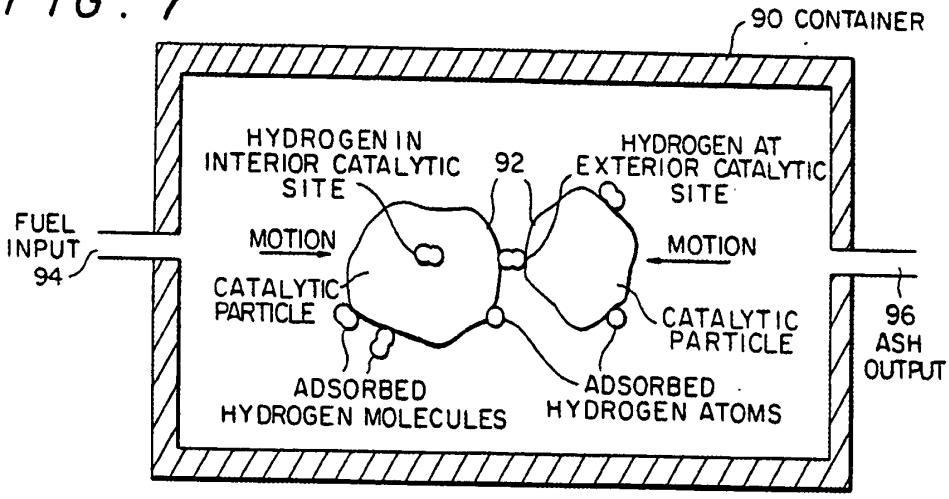
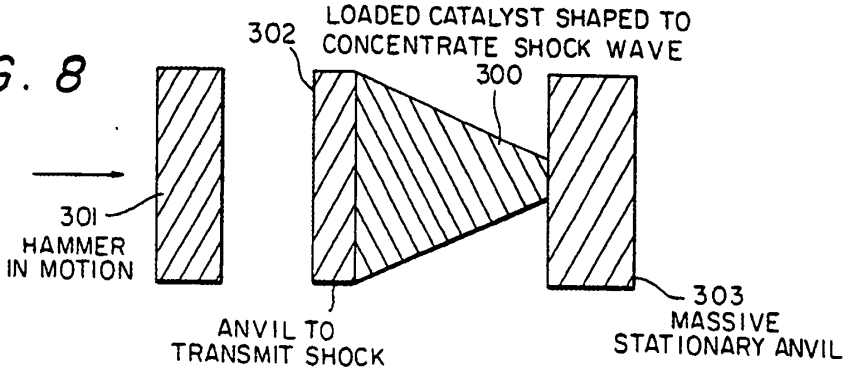
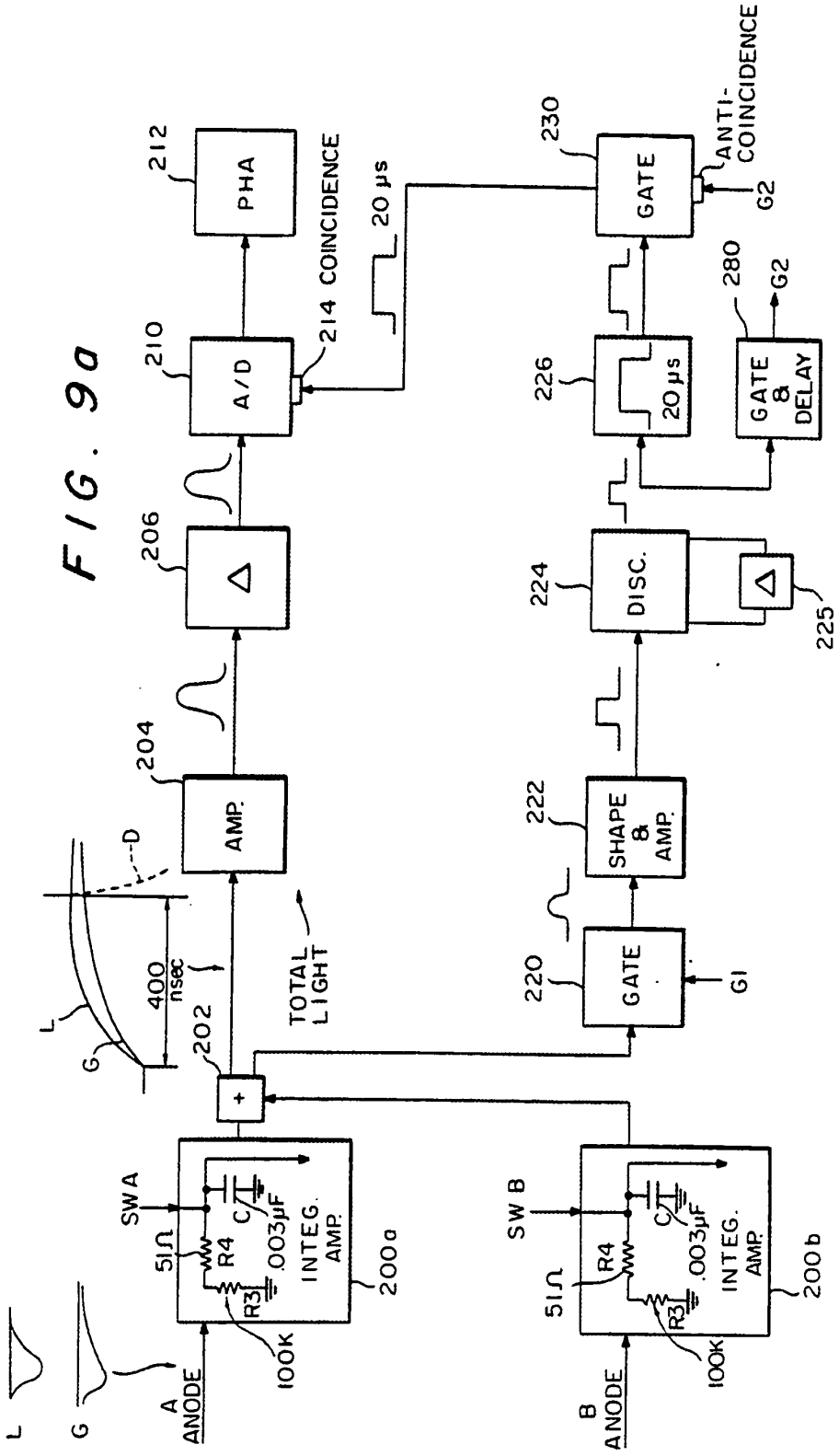


FIG. 8



4/3/06, EAST Version: 2.0.3.0

FIG. 9a



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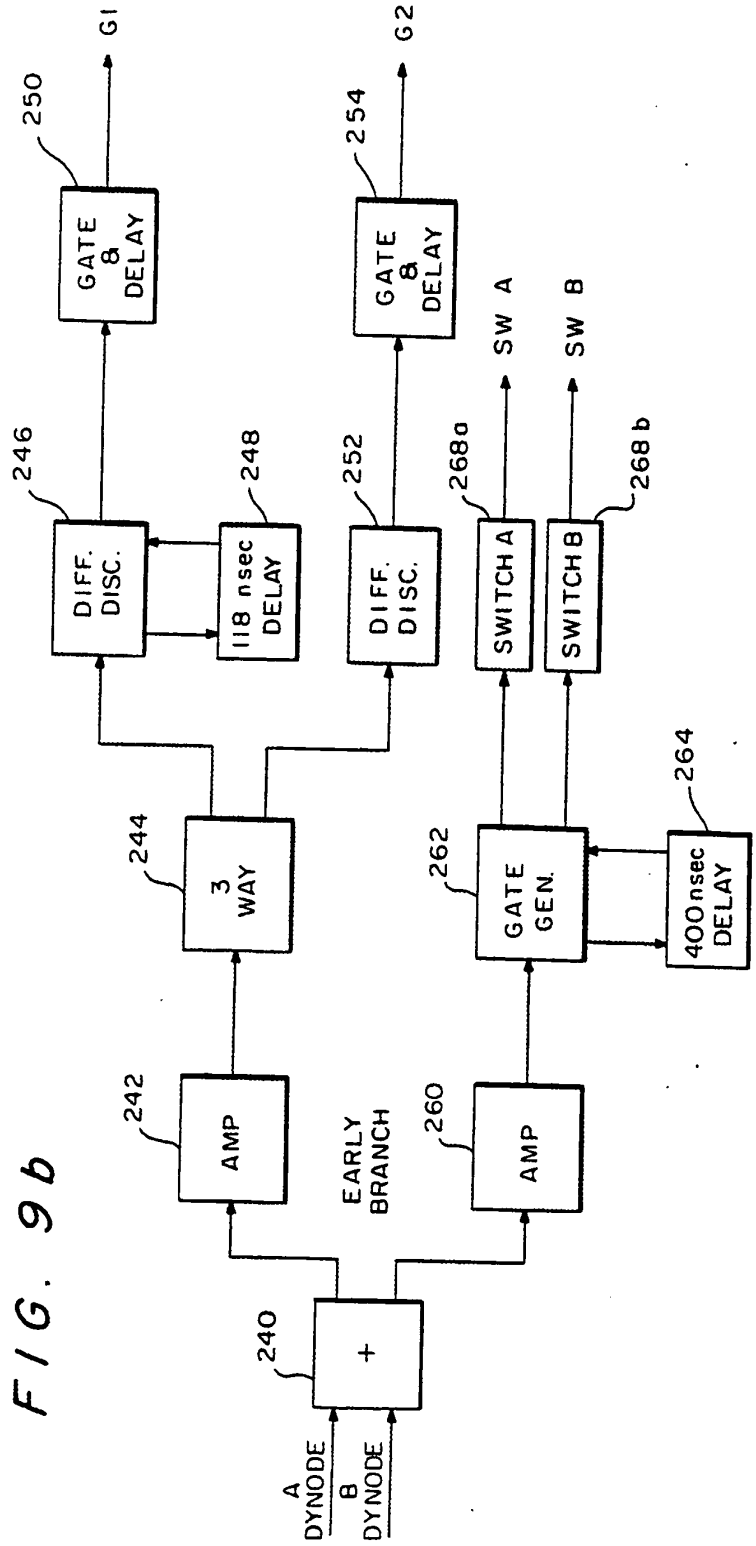
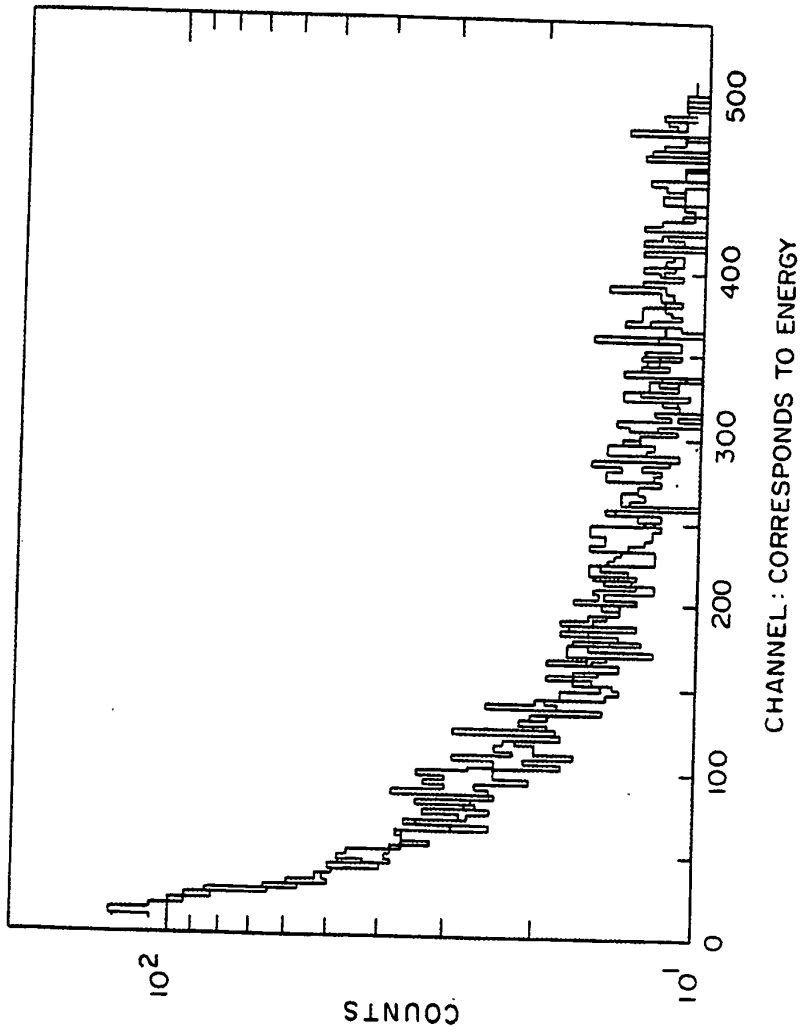


FIG. 9b

4/3/06, EAST Version: 2.0.3.0

FIG. 10


COUNTS
10^2
10^1
0
100
200
300
400
500
CHANNEL: CORRESPONDS TO ENERGY

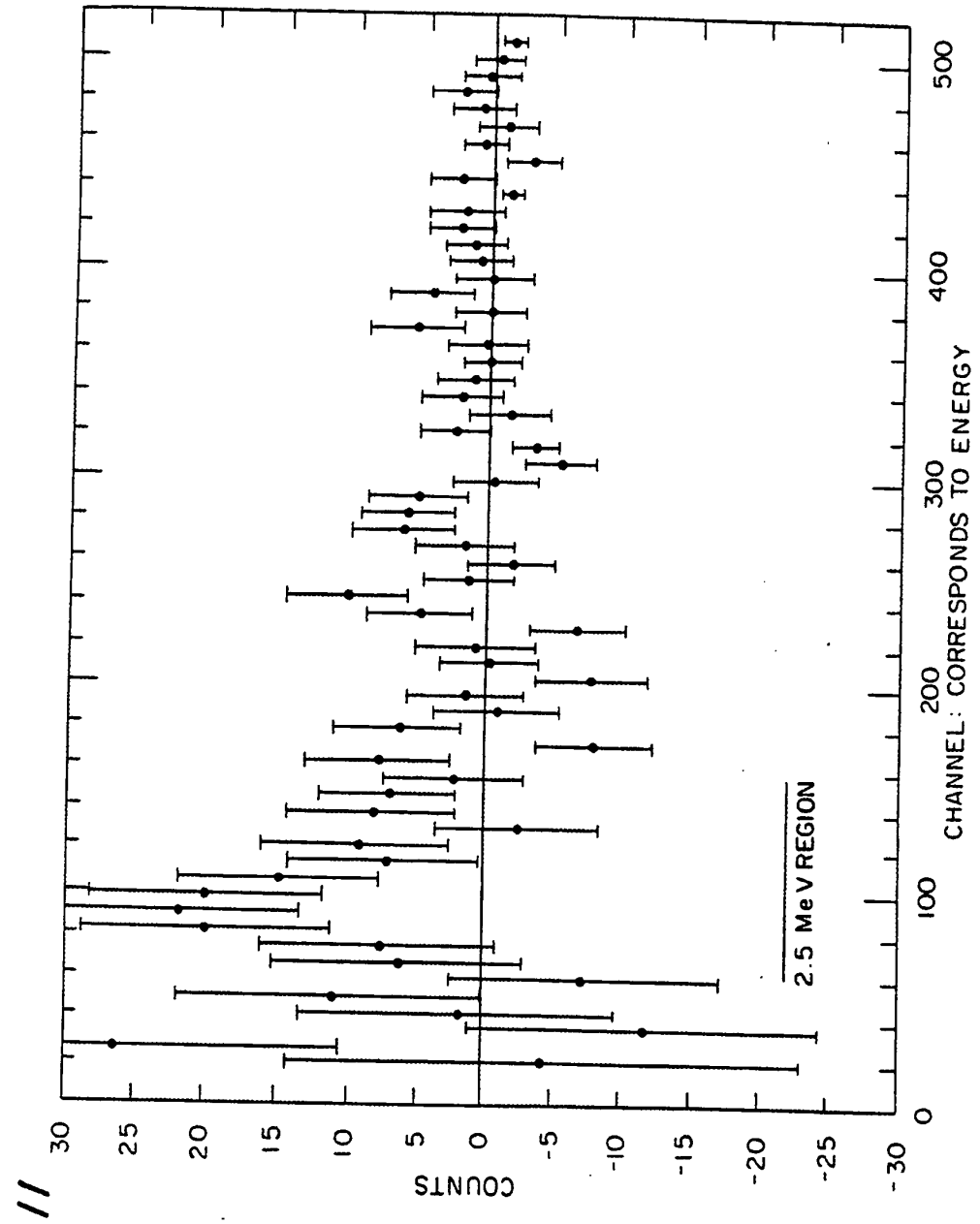


FIG. 11

4/3/06, EAST Version: 2.0.3.0

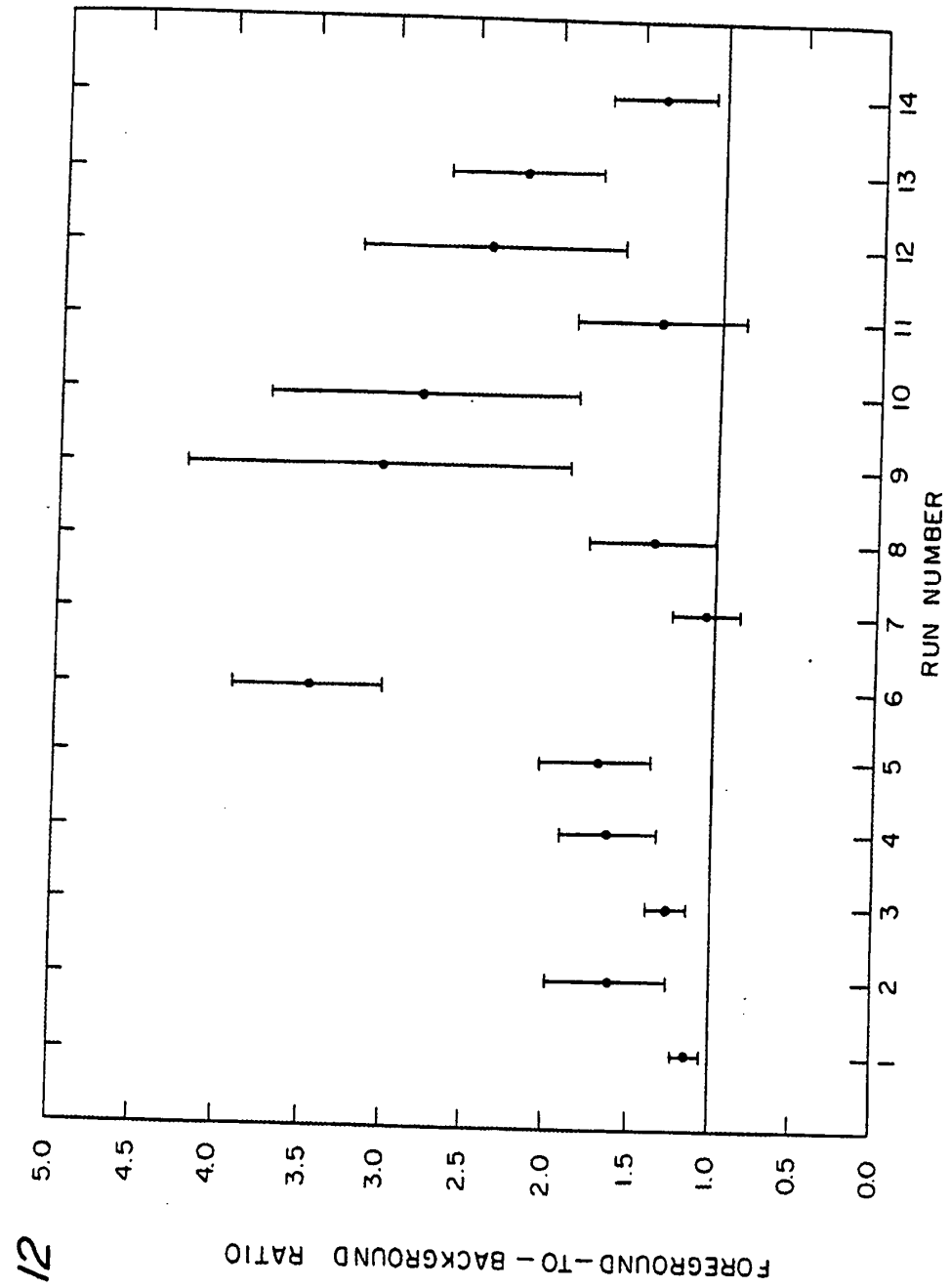


FIG. 12

4/3/06, EAST Version: 2.0.3.0

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 89/01749

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[5]: G 21 B 1/00

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System [8]	Classification Symbols
IPC[5]	G 21 B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are included in the Fields Searched [9]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	Journal of Electroanalytical Chemistry, volume 261, no. 2A, 10 April 1989, Elsevier Sequoia S.A., (Lausanne, CH), M. Fleischmann et al.: "Electrochemically induced nuclear fusion of deuterium", pages 301-308 see the whole article	1-4,6,9, 14,15,17-19,30-36, 50-52,54, 55,59
Y		5,45,46, 53,60
	--	
Y	Techn. Bulletin, Engelhard Industries Ltd, volume 7, (1-2), 1966, Baker Platinum Divison, (Sutton, Surrey, GB), H. Brodowsky et al.: "Solubility and diffusion of hydrogen and deuterium in palladium and palladium alloys", pages 41-50 see page 41: "Phase boundary transition hydrogen transfer catalysis"; page 47: "Diffusion phenomena"; figure 7	5,45,46, 53,60
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* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
8th December 1989	-2. 05. 90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	MISS T. TAZELAAR

Form PCT/ISA/210 (second sheet) (January 1985)

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This International search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ....., because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim numbers ....., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim numbers....., because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. Claims: 1-19,30-36,45(*),46(*),50-55,59,60.
2. Claims: 20-29.
3. Claims: 37-44,45(**),46(**) / (*) As far as depending on 32,35.
4. Claims: 47-49,56,57. (**) As far as depending on 37,39,4
5. Claim : 58.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

Claims: 1-19,30-36,45(*),46(*),50-55,59,60.
(*) As far as depending on 32,35.

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fe: were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.